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Electric Furnace Production of Pig Iron and Pig Steel

Joseph William Richards

ELECTRIC FURNACE PRODUCTION OF PIG IRON AND PIG STEEL

By Jos. W. Richards*

Mr. President and gentlemen of the Society: It gives me very great pleasure to meet you again tonight. I spoke to a Pittsburgh audience about two years ago on the general subject of what electro-chemistry is accomplishing, discussing in general the different fields it covers. About a year ago I had the further pleasure of talking to you upon a more specific subject, on what electro-chemistry is accomplishing in Sweden and Norway, limiting myself to the industrial revolution which is being accomplished there by electro-chemistry and electro-metallurgy. Tonight I have selected a still more specific topic, namely, the electric furnace production of pig iron and pig steel. It is a great satisfaction to me to see that as the topics become narrower and more specific they seem to attract more attention from you. Therefore, tonight I shall deal specifically with the technical side of the process of the reduction of iron ores to pig iron and pig steel in an electrically heated furnace.

Not more than five years ago there was practically no literature, nor had anything been done, in this line. The only experiments that had been made were those at Sault Ste. Marie by the Canadian Commission, to determine as well as they could whether it was possible to produce pig iron from ore in an electric furnace. The furnace adopted was the simplest type, about the size and shape of a dry goods box, with an electrode hanging in the top and the ore shoveled in by hand. It was a primitive kind of electric furnace, and the data thus obtained were merely approximations. And yet, on the basis of the experiments at Sault Ste. Marie, of which the Canadian govern-

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ment published a very full and accurate report, it was proclaimed that the electric furnace production of pig iron should be commercially profitable operation in Canada.

It was the report of this Commission which attracted the attention and inspired the enthusiasm of some Swedish engineers living at Ludvika in Sweden, three young men named Groenwall, Lindblad and Stalhane, and they determined to try their hand at what could be done in the line of a really practicable furnace properly designed to reduce iron ores. They persuaded

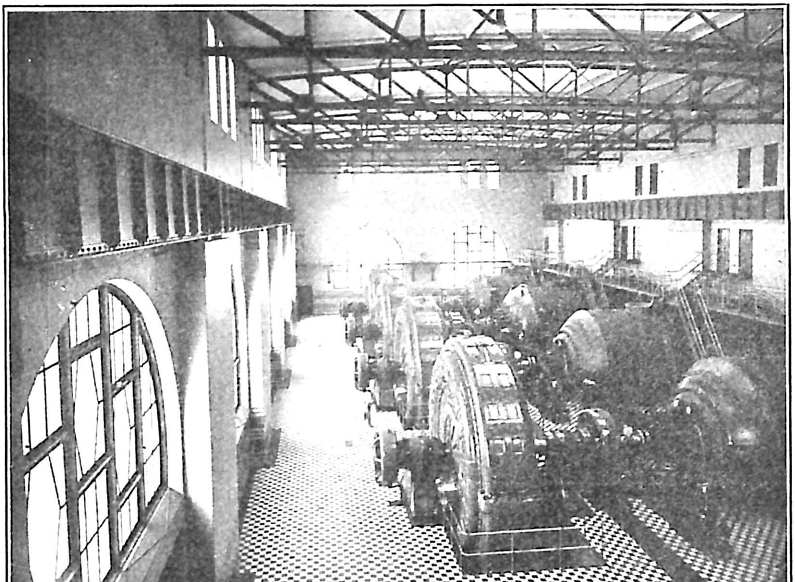

Fig. 1. Interior of Trollhattan Power House.
The Trollhattan power house is handsomely built of granite, and is run by the Government, supplying power at $12.00 per horse-power year to all the towns and cities in the vicinity.

the copper work's company at Falun, near Ludvika to back them up with money. They had to start without experience in this line, and also without the experience of any one else to profit by, and naturally made a great many mistakes. They worked for two years before they had a furnace that was measurably satisfactory. They had built five furnaces during that time and the cost of their experiments was nearly $200 000.

But they were upheld throughout by the conviction that they were embarked on an enterprise which was to revolutionize the iron industry of their native land. They saw clearly that Sweden had come nearly to the end of its career in manufacturing pig iron in the blast furnace. The reputation of Sweden for pig iron is based on the fact of their making charcoal pig iron, using the charcoal which they had in abundance. Within the past five years the price of charcoal in Sweden has doubled, and their manufacturers were facing the necessity of giving up the manufacture of charcoal iron. They could not import

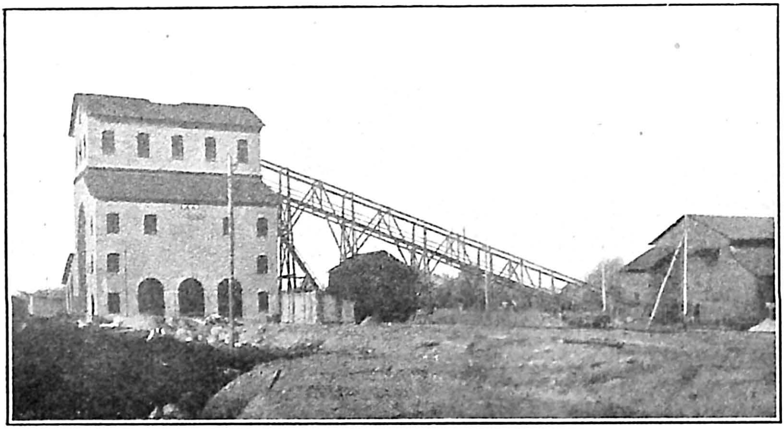

Fig. 2. Furnace Building, in August, 1910.
In August, 1910, the furnace building was nearly completed, the furnace being thus entirely enclosed. The ore and charcoal are brought up the incline to the charging floor.

coke, for such fuel would bring their pig iron in direct competition, as regards quality, with the rest of Europe. And these young men saw that the only salvation of their pig iron industry was to continue making pig iron by means of charcoal, and they saw in the electric furnace the only chance to save the industry. In the electric furnace only one-third as much fuel is required, per ton of iron, as in the blast furnace. In the blast furnace, if you use a ton of fuel to make a ton of pig iron, you are burning two-thirds of that ton of fuel to get the heat necessary to do the smelting and only one-third of the ton is used for the chemical reduction of the ore. If the electric furnace is used you need only that last third of a ton for its chemical reducing action, the use of the other two-thirds being displaced by electrically generated heat. Therefore, with a limited supply of charcoal it was possible to get three times as much pig iron from electric furnaces as from blast furnaces, and the cost of charcoal figures only one-third as much per ton of pig iron made in the electric furnace as for the pig iron made in the blast furnace.

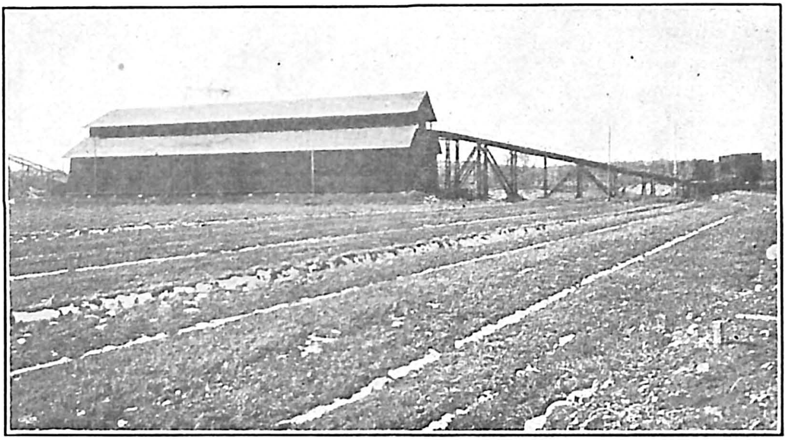

Fig. 3. Charcoal Store-house.

The various kinds of Swedish charcoal available for furnace use are stored in this building, a traveling belt carrying the charcoal up from the railway cars on the right, and trolley buckets conveying it up to the furnace, on the left.

In 1909 they had in operation their fifth furnace, which was designed to take 1500 horse power, and which ran at 500 to 800 h. p. for several months at Domnarfvet, where there are some blast furnaces and a steel works. Some of the best metallurgists in Sweden came to see the furnace and what was being done in it, and Prof. Odelsternja known to most of you as an iron and steel expert, certified that without doubt pig iron could be made in that small furnace cheaper than it could be made in their blast furnaces. That report was made about two years ago. This so interested the Iron and Steel Makers Association of Sweden, the "Jern Kontoret", that they decided at once to take up the matter. They first of all bought the patents covering this furnace, and having done this they appropriated $100 000 for experiments to build a furnace on a large scale, much larger that the one at Domnarfvet, to determine how it would work with the different ores and the different grades of charcoal which were available in Sweden. This action was based on the fact that their own experts had assured them that

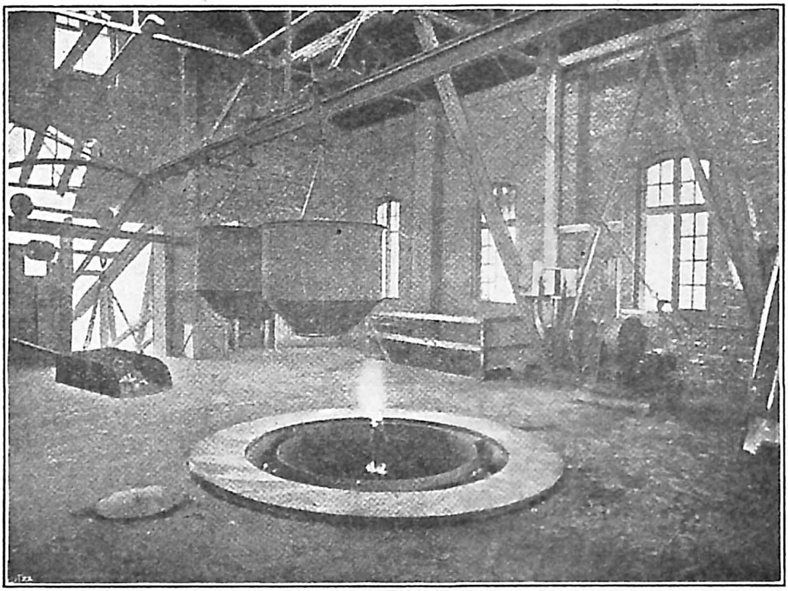

Fig. 4. Charging Floor of Furnace.
This view of the charging floor shows the charcoal buckets and ore shovel; also a pilot jet of burning gas above the charging cone of the furnace.

pig iron could be made cheaper in the electric furnace than they could make it in the blast furnace. I am not saying cheaper than *we* can make it in the blast furnace, but, as far as the Swedes were concerned, cheaper than they could make it in the blast furnace.

The Jern Kontoret was backed up in its endeavors by the government, because the latter recognized the national importance of saving the iron industry. The government therefore

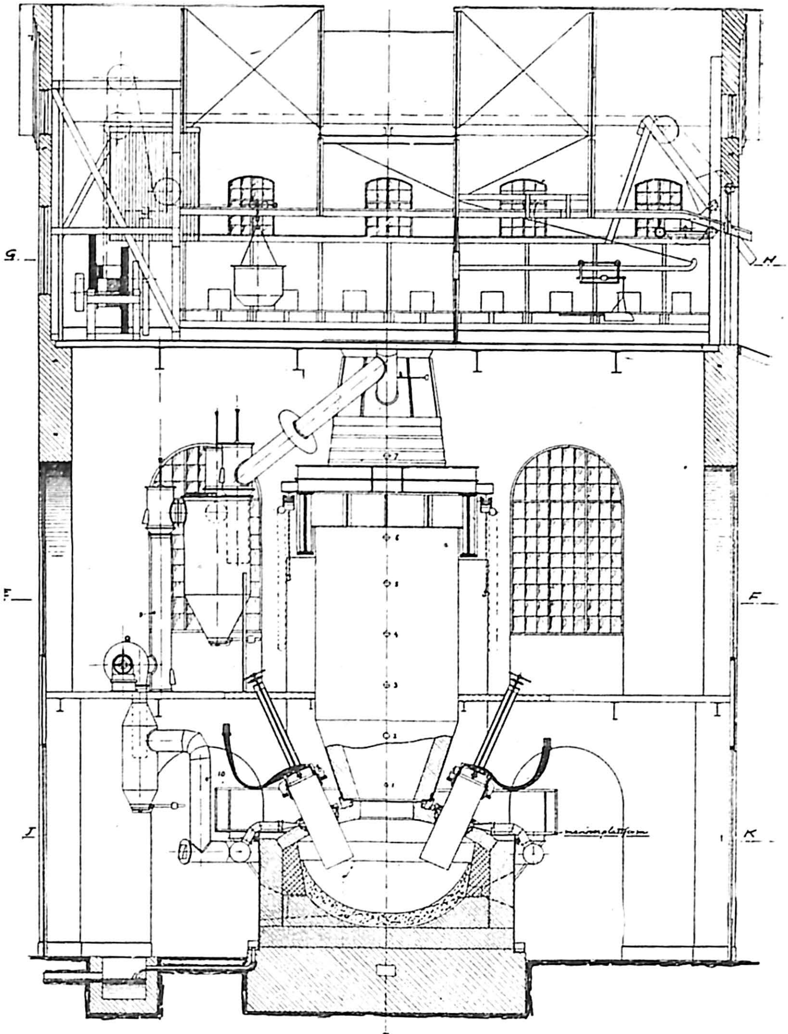

Fig. 5. Section through Furnace and Building.
Showing the gas circulation apparatus, with dust catcher, but with the old type of electrodes.

gave them practically free power for a period of two years at its plant at Trollhatten near Gothenberg, in Sweden. They erected there a furnace designed to take a maximum of 4000 kw., and erected a large charcoal storehouse, a laboratory, sending their best experts. Mr. Loeffler, the metallurgist of the

Jern Kontoret, was in charge, and the whole scheme was planned in a most scientific and intelligent manner.

The Trollhatten furnace has now been in operation for about a year and a half, and the results which have been obtained have met all expectations, and even more. The small furnace worked three years ago, which was intended to run with 1500 h. p., never was run continuously with more than 750 h. p., because of difficulties in the details of the furnace which had not been overcome. A furnace run at half its capacity does not run anything like as efficiently as one run at full capacity, as you know. Likewise the large furnace which was later put up has not been run at its full capacity because of difficulties in detail which had to be overcome. But there has not been a single difficulty which has not been successfully met and overcome. So, without any period of discouragement they have successfully mastered the difficulties which confronted them, and the furnace is working now better than ever before.

I want to give you the idea that this is a very infantile industry, for this is the first furnace of its kind. It is to be compared, as far as perfection is concerned, to the blast furnaces of perhaps 100 or 150 years ago, it is a first attempt to work out a problem on which there is no information, and the furnace has fulfilled all expectations. The published report which has been made shows the thoroughness with which the Swedes went into the subject. After the furnace had been running six months, with Mr. Loeffler in charge, he made a report to the Jern Kontoret, assisted by Mr. Odelburg and Mr. Nystrom, which is published in the Jern Kontoret's journal for 1911. It contains 226 printed pages, photographs and drawings of the furnace, and complete tables of all the observations and analyses which were made throughout the whole run. That report of itself tells of the seriousness and the earnestness with which the Swedes has taken up the subject; it means to them the saving of their pig iron industry. Unfortunately the report is in Swedish, so that it is possibly unavailable to most of you. Your announcement refers to some sources of information, and I would add one not listed there, a paper by Mr. Robertson of Toronto on "Recent Progress in Electrical Iron Smelting in

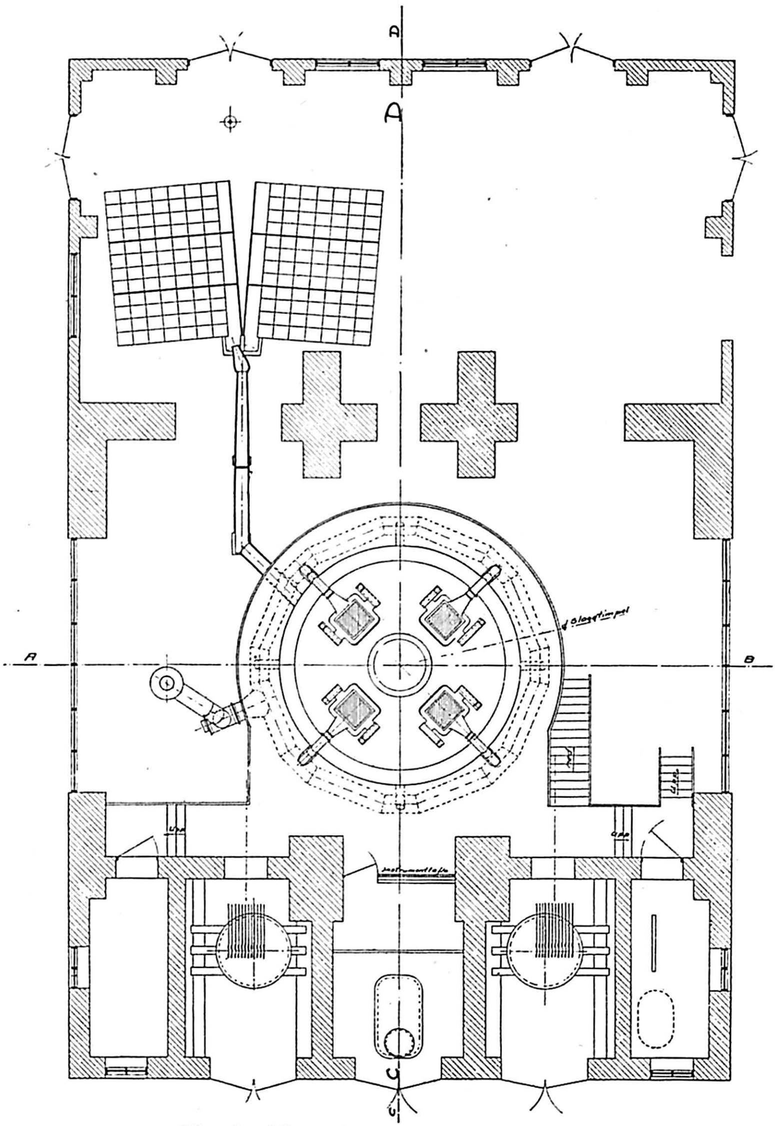

Fig. 6. Plan of Building. (first floor).

This plan shows the transformers, furnace at the level of the electrodes, and casting bed for pig iron and slag.

Sweden'', which was read before the American Electro-Chemical Society in its Toronto meeting, last September, and published in volume 20 of its Transactions. It is a paper of some 22 pages, abstracting the results which have been obtained at Trollhatten. The report is also noticed and partly translated, in abstract, in Metallurgical and Chemical Engineering of July and August of last year.

At the present time the furnace has been considerably improved, and is in operation and running with great satisfaction. When I was over there last summer Mr. Groenwall told me that he wanted to come over to the meeting of the American Electro-Chemical Society in Toronto but was too busy to come, as they were getting up plans and drawings for furnaces in several different places in Scandinavia, and said there would be 25 000 h.p. in operation in 1912 in several plants in Norway and Sweden making electric furnace pig iron.

I will now take up the summary of my lecture which has been printed and briefly speak to the different headings. The problem is the reduction of iron ore to pig iron and pig steel in the electric furnace compared with the blast furnace. The most important point is that the former requires only one-third as much carbon per ton of iron as the blast furnace. There is a peculiarity which any of you familiar with blast furnace work will at once understand, and it is an important one. It is this that when you reduce iron oxide by carbon, ($Fe_2O_3+3C=2Fe+3CO$) the maximum amount of carbon which can be used to reduce the iron oxide to iron is 36 carbon to 112 of iron. Not only is it useless to put more carbon into the furnace than is thus theoretically required to reduce the iron oxide, but it is absolutely prejudicial to the running of the electric furnace. If you are running a blast furnace you can make a ton of iron with a ton of coke, and if you are foolish enough you can put in a ton and a quarter or a ton and a half and it does not hurt the furnace. The latter works hotter, but it does not stop the operation. If you put in more carbon than is necessary in the electric furnace the operation stops. The furnace gets a bad fit of indigestion. The carbon accumulates because there is no oxygen to burn it. The only source of oxygen to consume the carbon is that in the iron ore itself, and since it requires theoretically 32 parts of carbon to reduce 100 parts of iron, there is no need of putting any more in; and in fact if you do put more in, it stops up the furnace because it accumulates therein.

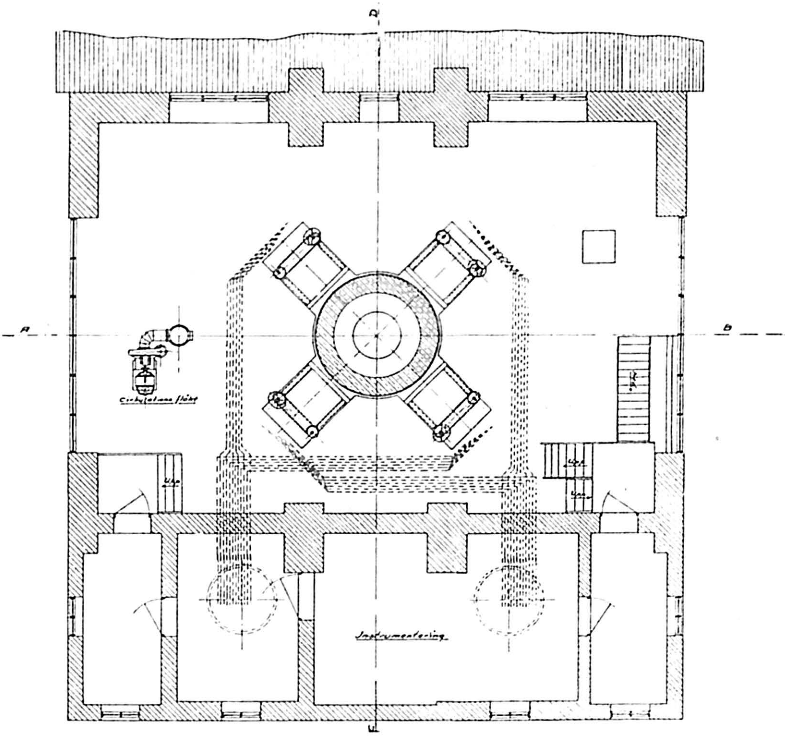

Fig. 7. Diagram of Electrode Connections, using four Electrodes. Detailed diagram of electrical connections from the transformers to the four furnace electrodes.

The early experimenters on electric reduction of iron ore did not understand and did not appreciate the importance of this fact, and that gave them most of their difficulties. They appreciated that it would not require as much carbon in the electric furnace as in the blast furnace, so they put in half as much, and the furnace worked, although rather poorly. When they cut down the carbon it worked better; every time they cut down the carbon and got nearer to the proper point the furnace worked better, and without exception the product per horse-power-year was greater. The amount of carbon must be closely regulated in order not to use too much. Appreciating that fact, a ton of pig iron can be made with about a third of a ton of charcoal; and the more charcoal used above that, the more difficulties arise in running the furnace. When carbon accumu-

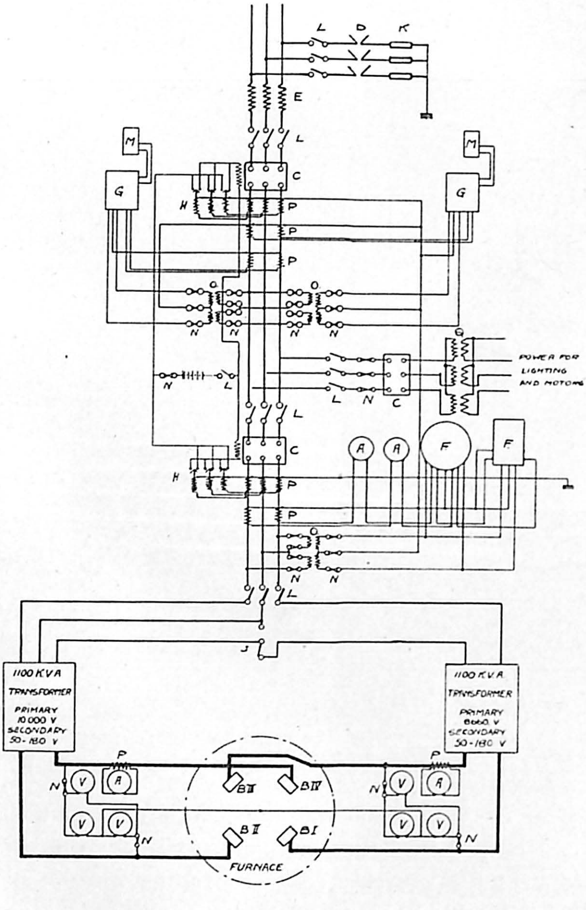

Fig. 8. Diagram of Electric Apparatus.

This diagram will show to electrical engineers the electrical equipment, from the three-phase high-tension supply to the two pairs of electrodes used to operate the furnace.

lates in the lower part, it lowers the electric resistance of the furnace, makes it difficult to keep it hot, and the best remedy is a dose of iron oxide without any carbon. That acts as a mild purgative, and the furnace is cleaned out of the carbon which has accumulated, and is put back into proper working order again. All that is entirely different from blast furnace practice; and I think it was the non-appreciation of this fact which made a good deal of the difficulty met by the early experimenters.

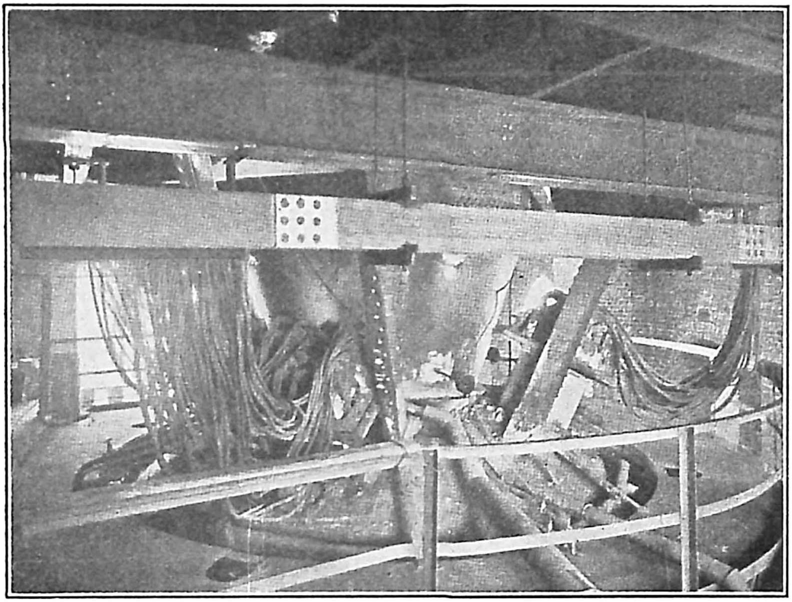

Fig. 9. The Roof of Crucible, showing Electrode Connections. Showing the top of the arch over the crucible and the flexible cables from the buss-bars to the electrodes.

I have so far spoken only of the maximum amount of carbon that can be put in. But in the electric furnace we do not produce gas which is entirely CO, we produce also CO_2. If one produced all CO_2 (which is impossible) it would only require half as much carbon. You cannot produce all CO_2, but you do produce somewhere about half of one and a half of the other. Then you need about ¾ of the stated amount of carbon, in actual practice, when you get down to real working conditions.

Now not only should one be sparing in regard to the amount of fuel charged, but there exists an anomaly which I will try to explain. Having a fixed weight of oxygen to be taken away from the iron, if you take it away by carbon forming CO, the formation of this CO gives a certain amount of heat, contributed to the furnace. If you get some of it changed to CO_2 you get more heat contributed to the furnace, because when carbon unites with oxygen to form CO_2 it gives out more heat per unit of oxygen combined than when it forms CO. Therefore the *less* carbon is used in the furnace the *more* heat of oxidation you get from it. I do not know whether I have made that clear. A fixed weight of oxygen gives more heat when it forms CO_2 than when it forms CO and requires less carbon to combine with. Therefore as you get more assistance from the carbon the less you can use, of course down to the limiting amount. Further, the more heat assistance you get from the carbon the less electric power you have to use. So that the less carbon you can get along with in the furnace for reduction, the more assistance you get from it in a thermal sense, and the less electric energy you have to use per ton of pig iron. All the experiments that have been made, and all the work of the Swedish furnaces confirm this principle. As they reach economy in carbon and use less fuel, they also use less electric energy, and they thus save at both ends.

Power Consumption: The power actually required by this Swedish furnace has been about one-third of a horse-power-year per ton of pig iron. Speaking of the Trollhatten furnace, I was asked to calculate the theoretical limit which it could reach if the furnace were run as economically as possible. I made a calculation showing that when they obtained good efficiency from the carbon, using the least carbon that was necessary for reduction, and were running the furnace at high capacity, i. e., driving it so that the radiation losses were at a minimum, I believed they could reach one-fourth of a horse-power-year per ton of pig iron, and the lowest limit I placed at one-fifth. They have reached one-fourth of a horse-power-year per ton at times, for a period of a week or more. The first week in last September the furnace was working well, and they then reached four tons of pig iron per horse-power-year. I think that when a large furnace of perhaps a hundred tons daily capacity is built, and is run with the knowledge which

Fig. 10. A new square Electrode.
Showing a square, built-up electrode, with end connection, before putting into action.

will exist within perhaps five years, they will probably reach five tons of pig iron per horse-power-year.

The variation of power with the size of the furnace is very marked. The smaller the furnace the larger the power requirement per ton of pig iron produced, and as we increase the size of the furnace it will undoubtedly reach greater economy, as I have just indicated.

Consumption of Electrodes: This is one of the items which gave great concern. The electrodes used are very large, and making connection with the top of the electrode it could only be used down a certain distance in the furnace when it became so short that it had to be taken out and about half of the electrode rejected. The consumption of electrodes working in that way was about 12 percent of the weight of the pig iron produced, while the actual burning away of the electrode was only half that, and the stump weighed the other half. Within the last two years the manufacture of electrodes has been improved very much. They are making electrodes 24 inches in diameter, and six feet long, of splendid quality, fitted with a screw and socket so that they can be screwed into each other, end to end. When the electrode is down as far as it can go a new electrode is screwed onto the top of partially used one, and thus the butt is entirely used. They are cemented together with a little graphite paste and there are no longer any butts. This device alone, at once cut in half the consumption of electrodes, so that it amounts now to only five percent of the weight of the pig iron produced, and this has reduced considerable a large item of expense.

Circulation of the Gases: Concerning this I wish to make explanation. In a blast furnace which is receiving air, the current of the blast, weighing five or six times the weight of the pig iron produced, carries the heat which is generated in the lower part of the furnace with great speed and effectiveness into the upper part of the furnace, and thus heats the upper part. In the electric furnace the gases produced, instead of weighing five or six times the weight of the pig iron, weigh less than the weight of the pig iron. There is practically no nitrogen, but only the CO (and CO_2) formed from the reduction of the ore; and this, passing up the furnace, has only a small heat-carrying capacity and does not carry to the upper part of the furnace the heat generated in the lower part by the electric energy, in any way comparable to the distribution of heat into the upper part of the blast furnace by the blast and gases.

This is a difficulty which entails serious consequences. We know that in a blast furnace the larger part of the reduction of the ore takes place in the upper half of the shaft. It is reduced by the *CO* gas formed at the tuyeres rising into the upper part of the furnace. But, to get a similar desirable utilization of *CO*

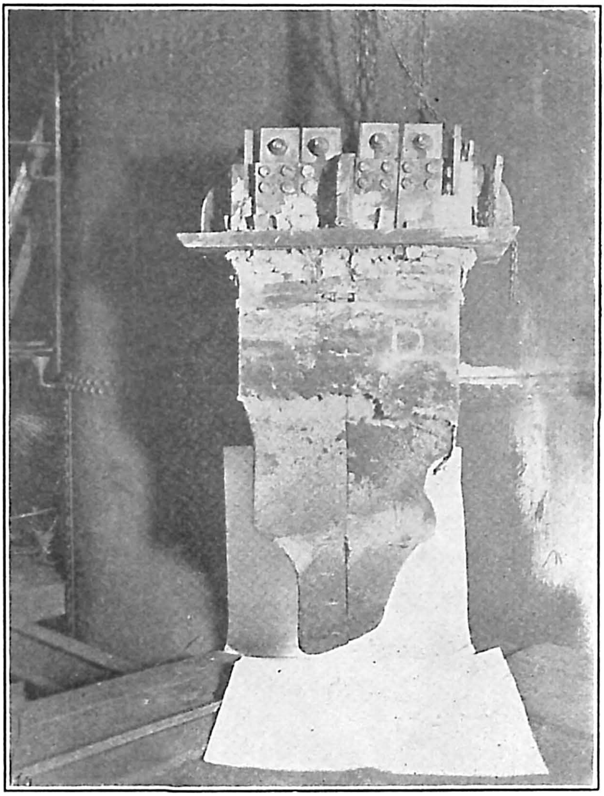

Fig. 11. Electrode half consumed.
A square, end-connected, built-up electrode after use, showing the large amount of unused butt and the consequent waste.

in the electric furnace, the upper part of the furnace must be warmed so that the temperature is a low red heat, at and above which reduction by *CO* can take place. The Swedish engineers thought a great deal over the question of how to carry the heat from the crucible of the furnace up into the shaft, in order that the shaft of the furnace should be kept hot enough for reduction by CO to take place. And they have met it by repeated circulation of the gases, but I do not think they have solved it in the best way. They bring down some of the gas from the top of the furnace and blow it in at the bottom under the arch of the crucible. Half to two-thirds, and even three-fourths of the gas produced is thus blown back again and sent in at the lower part of the furnace. With this arrangement there is passing up the shaft of the furnace two to four times as much gas as would normally pass up, and this carries two to four times as much heat from the hot zone at the bottom of the furnace into the shaft, raising the temperature of the shaft much higher than it would be without this system. They regard this system of circulating the gases as being necessary to economy in the furnace, because it permits greater reduction of the ore by CO, thus utilizing the CO gas in the upper part of the furnace.

I will interject here an idea which I think will solve the problem in another way. Abandoning the circulation of the gas, the shaft could be heated more economically by an auxiliary system of heating. If they were to jacket the furnace shaft with combustion chambers in which gas is burnt, or heat the furnace shaft up to low redness by electric heat (often the cheapest source of heat) it would be possible to thus warm the shaft to the reducing temperature of the ore and thus utilize the ascending CO by making it reduce iron ore. The circulating system is the first attempt to solve the difficulty of distributing the heat into the shaft of the furnace, and it has several disadvantages. One is that the CO_2 in the gas that has been formed, coming down and going into the furnace crucible, attacks the electrodes. It attacks the carbon in the charge which ought to be reducing iron ore, and consumes it. If the gas were only CO it would not matter so much, but it is partly CO_2 to start with, and putting that CO_2 at the bottom of the furnace is highly undesirable. Another difficulty is that there is always moisture in the charge and also raw limestone. Then, of the CO_2 from the limestone, and moisture from the ore and charcoal which thus go into the circulating gases, half to three quarters are sent down into the bottom of the furnace. The H_2O and CO_2 thus sent down are decomposed by the carbon chilling the furnace where it should be hottest, and consuming carbon. I discussed the question of circulating the gases with Mr. Loeffler, and I think the remedy adopted is a rather illusory one. It

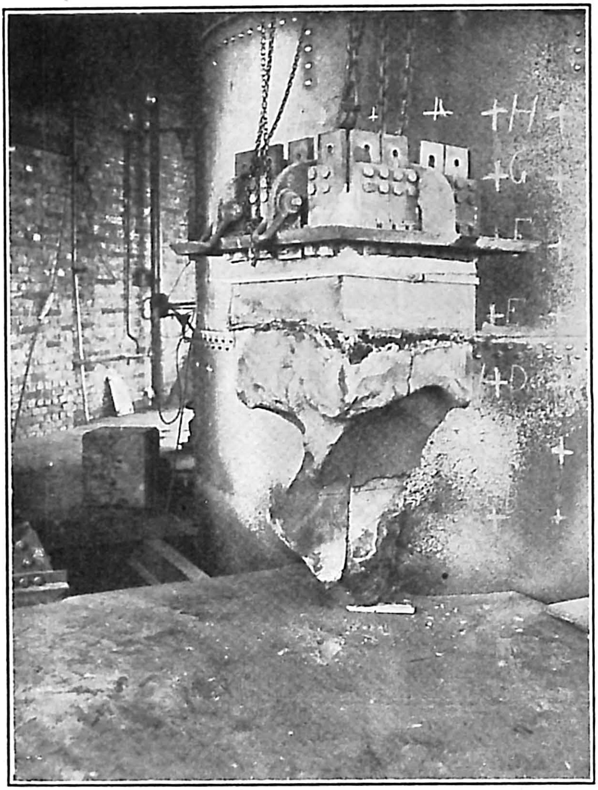

Fig. 12. Electrode on removal.
A square, end-connected electrode used to the limit with small point only just touching the furnace charge, when in use.

should be abandoned, and I believe they will finally adopt some such system as I have suggested for getting the upper part of the shaft to a temperature sufficient for CO to reduce the ore. Then you can dispense with the elaborate system of circulation of gases and the use of a fan.

Composition of the Slag: The furnace is lined with fire-brick down to the crucible, but the crucible is lined with magnesia. Therefore you have an entirely different condition from the ordinary blast furnace, which has a silicious lining around the crucible. You have a basic-lined furnace at the crucible and the slag can be made so basic with lime that it takes out sulphur and even some phosphorus from the ore and makes the pig iron much lower in sulphur and even lower in phosphorus than ordinarily.

Properties of the Product: The pig iron produced has been the equal in all respects to Swedish charcoal pig iron, without any qualification. Some steel makers who have used it said it was better and they attributed this to the fact that it did not appear to contain any oxides or nitrogen. Nitrogen is more or less speculative, but it certainly does not contain the oxides which are frequently present in pig iron, having caught them by oxidation from the blast as it passed the tuyeres. The product is therefore more free from oxides and nitrogen than ordinary pig iron, and when it comes to making fine steel these qualities count heavily.

Pig Steel: By cutting down the amount of carbon used for reducing, the furnace worked better, consumed less power and less carbon, worked more rapidly, and produced a pig iron that was white instead of gray. You all know that as you run the blast furnace faster the tendency is to make white iron. By reducing the amount of fuel, and running at a lower temperature, a product was obtained with 0.1 percent silicon, 0.1 percent manganese, and as low as 1.5 percent of carbon. Mr. Greonwall said to me "What are we going to call that metal? Shall we call it pig iron?" I said "No. That would be a misnomer. Call it pig steel, because in composition it is simply steel." So that is what pig steel is. It is a metal with 2.2 percent or less of carbon, a very small amount of silicon and manganese, low in sulphur and phosphorus, made directly from iron ore in the electric pig iron furnace. It is not pig iron, it is really crude steel, so we have called it pig steel, a name which has been generally accepted. Its German equivalent is "Rohstahl" and in French "Acier brut."

Now as to the advantages of this material? When you are going to make steel out of pig iron you have a metal which is 92 to 94 percent iron and the rest impurities which have to be taken out in the steel furnace. If, instead of 92 to 94 percent iron you get a metal with 97 or 98 percent iron there are only

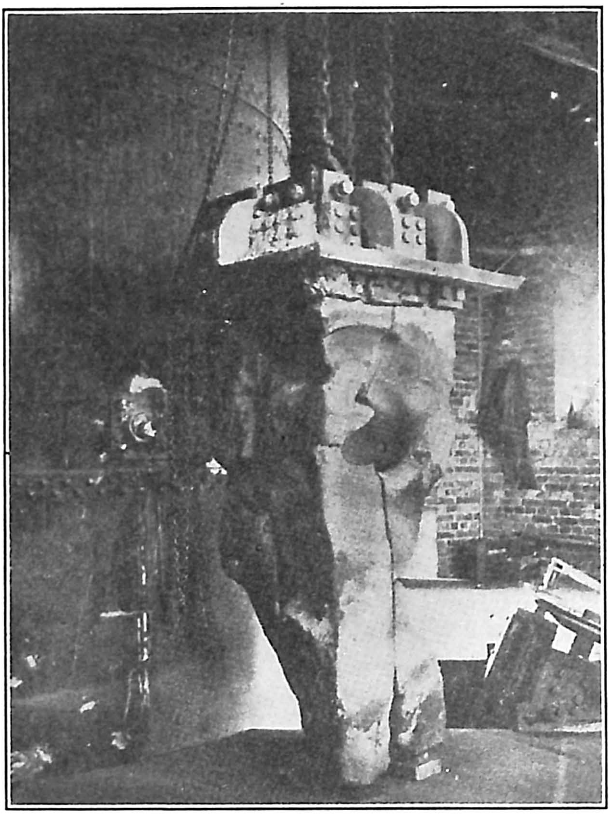

Fig. 13. Electrode burned by CO_2 gas.
An electrode perforated by a current of CO_2 in the cool, circulating gas, from a misplaced gas nozzle.

two to three percent, or less, of impurities to remove in the steel furnace. The steel workers found out at once its advantages. Put it into open-hearth furnaces, and with half or less of the ordinary refining it is converted into steel. The output of open-hearth furnaces using that material is increased nearly

50 percent. That problem seems as simple as *a b c* now it has been done. The discovery was more or less accidental, but it did not takes the Swedes long to appreciate the immense importance of having crude material which they could convert into steel so easily that it nearly doubled the output of their open-hearth furnaces and also increased the output of their electric pig iron furnaces. The pig iron furnace made more of this pig steel in a day than it did of pig iron, and at less cost; the steel furnace made more steel per day from this material and at less cost. This rather accidental discovery has completely absorbed the attention of the Swedes and Norwegians. They say that not only have they a new process for making pig iron cheaper than the blast furnace, but they can make a product which they never could make in the blast furnace which is dollars a ton cheaper when converted into steel.

This is the final stage of the problem as I present it to you tonight. Great energy will soon be directed to making pig steel and it will cheapen the manufacture of Swedish and Norwegian steel very considerably. This electric furnace pig iron and pig steel has been converted into finished steel in the open-hearth furnace and also electric furnaces in Sweden and Norway, and the report of the Jern Kontoret shows that it has been equal in results to the best charcoal iron that is made in the blast furnace. Some of the steel makers have said that they think it is better. None of them have said that it is inferior. So there is no doubt that this material will take its place as a proper steel making material.

I think that this presentation of the subject will convince you that our friends in Sweden and Norway are living up to their reputation of being progressive iron and steel metallurgists. We all know that whenever we have met them here as iron and steel men, they have shown that they know their business thoroughly; and I have great confidence in the outcome of this new departure, because the Swedes have taken it up in a most conservative and yet a most progressive manner. They have done it in a manner which commands our admiration for their scientific skill and for their earnestness, and they are going to carry it through to a satisfactory conclusion, there is no doubt about that. In fact at the present time every report we get from Sweden says that the production of pig iron in the electric furnace is to be the future method of manufacturing pig iron in Sweden and Norway. They are not saying much about pig steel. I have enlarged upon that here, but our Scandinavian friends have been rather keeping that to themselves as a supplementary or collateral matter which came to them

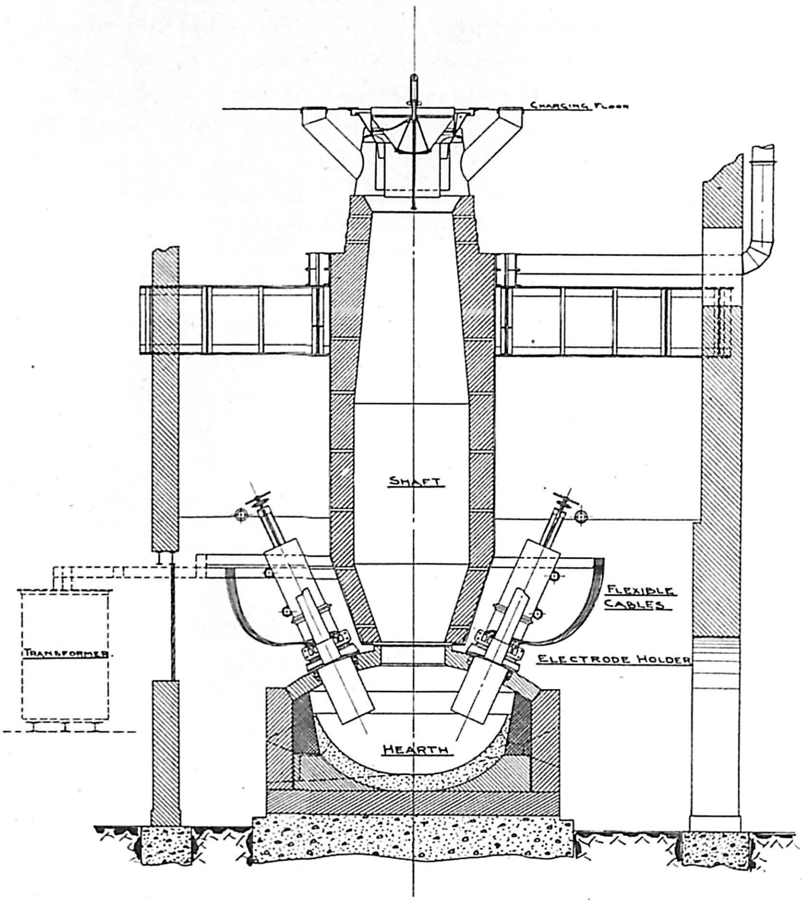

Fig. 14. Section showing new Electrodes and holders.
Showing the new, round, monolithic electrodes, with permanently placed connection against arch of crucible.

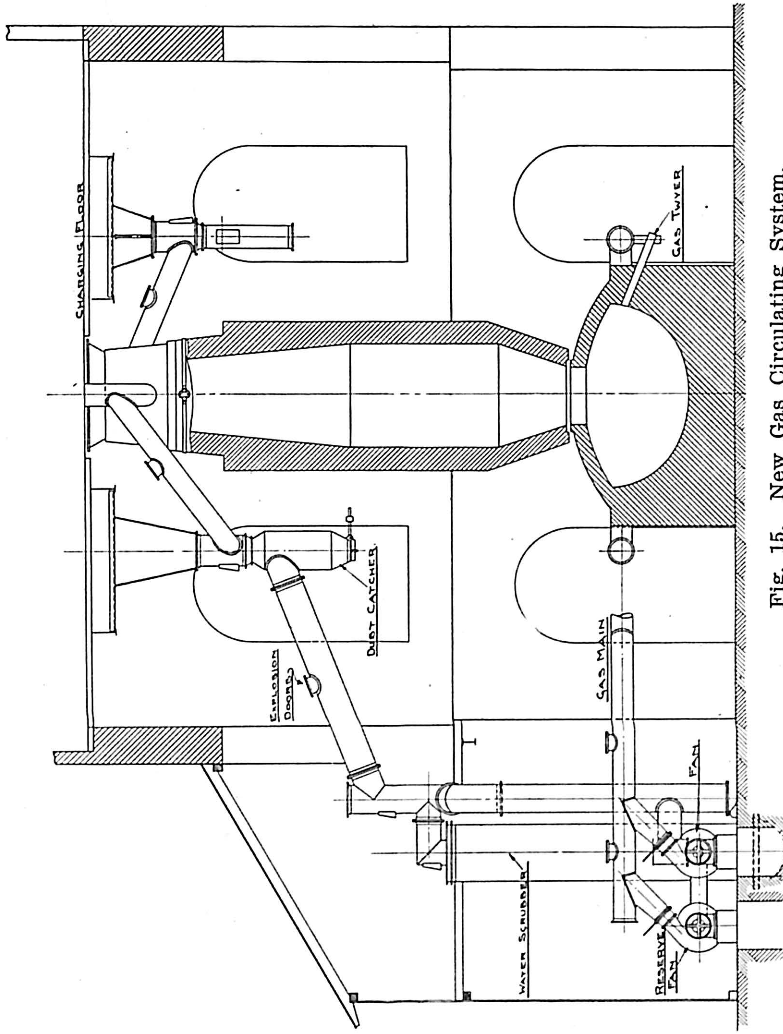

Fig. 15. New Gas Circulating System.

The new gas-circulating system with scrubber to remove moisture, thus saving heat to the crucible of the furnace.

unexpectedly and which is perhaps going to be as large an advantage as the main one of making electric furnace pig iron.

I am often asked whether Pittsburgh is ever going to see an electric pig-iron furnace, and I have answered that by saying that I do not believe it will, because with coal and coke at the prices you have them and with power generated by steam or gas, you cannot make pig iron here in the electric furnace as cheaply as you can make it in the blast furnace. But when one has the possibility of making in the electric furnace, directly from the ore, a metal which can go directly into the open-hearth furnace and which requires 50 percent less refining than pig iron does, it commences to put another face on the question, and makes one pick up his pencil and commence to figure as to whether such a thing is not possible. About all I am prepared to say now is that I think it will be worth the while of the Pittsburgh iron and steel men, in the near future, to figure out whether it will not pay to make pig steel in that way in the Pittsburgh district. I thank you very much for your close attention.

DISCUSSION

President J. O. Handy: I am sure we have all appreciated this most interesting address of Dr. Richards and I feel quite sure that Dr. Richards will be glad to answer questions. The electric furnace pig iron industry does not exist in Pittsburgh and the electric furnace production, or refining, of steel is very new to us.

I would like to ask what the approximate cost of production of pig iron in Sweden is at the present time?

The Author: They figure on the small furnace at Domnarfvet that they could make pig iron at $1.50 less a ton than they could in their own blast furnaces. I can only give you comparative figures; I gathered from what was told me that they were figuring on this new furnace of 4000 kw. making pig iron at $2.50 a ton less than they could make it in their blast furnace. You can only make the comparison with their own furnaces, and I think that is a satisfactory answer because if you know what it costs in their blast furnaces you can subtract $2.50.

President J. O. Handy: Is the electrode consumption a very large factor? The power cost must be very small with a power cost between $4 and $8 per h.p. year and four tons of pig iron produced per h.p. year.

The Author: With four tons of pig iron made per h.p. year the power cost in Sweden would be about $2 per ton, not more.

The electrode cost—five kilo. per ton—at 3c a pound, would be 33c per ton of pig iron. The charcoal cost is 1/3 ton of charcoal, though formerly costing $6 per ton, which in Sweden now costs $12 a ton, so that the charcoal would now cost $4 per ton of pig iron. Then you can add to that the ore and the labor and get the approximate total cost. But the real factor is that they substitute for 2/3 of a ton of charcoal, costing $8, one quarter of a h.p. year costing $2, and the cost of electrodes. Of course, the furnace is being run on a smaller scale than a blast furnace. A furnace of 2000 kw. produces about 18 tons a day. What sort of economy could be had in a blast furnace producing 18 tons a day? The comparison with the blast furnace will become more interesting when we have an electric furnace making 100 tons a day. I can say that the possibilities of economy in the electric furnace will amount to several dollars per ton before they get through with it, in the next few years.

President J. O. Handy: I suppose the conditions in Canada would permit the profitable making of pig iron by the electric process while the conditions in the United States would not?

The Author: It happens that the United States has a furnace manufacturing pig iron which is almost exactly the same kind of a furnace as the Swedish. It was developed indedendently by the people out in California, and it is now making iron which is being sold in San Francisco. They say they can sell it in San Francisco cheaper than the eastern iron can be brought over there. This small furnace in Shasta County, California, is almost identical in shape and appearence with this one in Sweden. Our Swedish friends thought the Californians had gone over and stolen their plans, and accused them of it; but after one of the Swedes came over here and met Mr. Noble they were convinced that it was an independent development, and they have come to an agreement whereby the Californians agree to stay in the West and the Swedes will nandle the rest of the country.

Mr. F. T. Snyder:* I did not come down from Chicago to talk but to listen to Prof. Richards tell about this electric

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pig steel that is arousing so much interest. It has proved of decided interest to me when considered in connection with some results that we are getting in the 500 h.p. electric steel refining furnace which is operating commercially in Chicago on castings. The records of this furnace seem to show, that in a properly designed furnace, metal can be melted from the cold and refined electrically at a cost very close to the open-hearth cost for the same service and output. Added to the figures Dr. Richards has given us for the cost of making pig steel, it begins to look as though the cost of making steel electrically in this country all the way from the ore to the ingot, is at present not a very long way from being as low as the cost by the present blast furnace and open-hearth combination.

Prof. Richards did not tell us how much nitrogen there was in the Swedish output. I should like to inquire regarding that point.

THE AUTHOR: I have not seen any determinations of nitrogen in it. It would certainly be less than in the ordinary pig iron or in blown bessemer metal.

MR. F. T. SNYDER: This is something that there is not a great deal known about, but it seems to be a fact that the electrically refined steel is tougher and more resistant to shock than steel which is made in furnaces where a great deal of nitrogen comes in contact with the steel. Whether that is due to a friable iron nitride segregated between the crystal faces or not is a problem that there is a great deal of work to be done on. If it is true that you can make electric steel at a cost which is somewhere in the neighborhood of open hearth cost it becomes a matter of great interest in the question which is now being considered in the East as to whether electric rails are not a commercial possibility. If a rail can be made which will break perhaps half as often as an existing rail of the same specifications we have a situation which ought to be interesting to the railroads and to the steel producers. Dr. Richards is probably in a very much better position than I am to prophesy as to the quality but in our small work we have found that steel castings made from pig iron in electric furnaces are distinctly tougher and more resistant to shock of all kinds than castings made from a similar pig in the open-hearth furnace.

MR. FRANK GARRATT:* I would like to ask Dr. Richards what the percentage of iron the slags carry when making the low carbon product of which he spoke, i. e., the pig steel as he terms it?

THE AUTHOR: It is higher than when they are making the higher carbon product, but even in that case it is low. I cannot give the figures without looking it up; it is not a high amount. It is not higher than is often produced in the blast furnace.

A MEMBER: I would like to ask Dr. Richards whether any other types of furnaces were considered beside the resistance type, which I presume this one is.

THE AUTHOR: This is the resistance type. I have given you mostly the work of these Swedish investigators. There has been some steel made directly from the iron ore, but very little, by Stassano in Italy in an arc furnace, but that cannot compare in efficiency with a shaft furnace of this kind. That is operated by radiation from the arc, and at a considerably higher cost. The Swedes have not worked with the arc; they have considered only the resistance furnace, the material to be smelted forming the resistance between the electrodes.

A MEMBER: Do they have any trouble starting the furnace?

THE AUTHOR: In starting the furnace they fill the lower part with coke and then blow in air to get it started and warmed up; then above the coke they charge in their regular charges and it starts up quickly making pig iron. I think within six hours of starting they have pig iron flowing. It is surprising how smoothly the furnace works. It is a great tribute to the ability of the Swedes to start up a furnace of this kind with a dozen or a score of new conditions and to have succeeded as smoothly as they have. They have hard work to prevent themselves from getting enthusiastic—something a Swede very seldom becomes.

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MR. H. C. CRONEMEYER: What voltage and current are used in these furnaces?

THE AUTHOR: Those details I did not take the time to tell. There are probably ten facts that might be told for every one that I have told you. The voltage used is regulated from 90 to 50 in their transformers, allowing them to start at 90 and regulate down to 50 volts. The amperage is I think from 10 000 to 14 000 on each electrode. They use 2000 kw., and at 50 volts you can see that would be 40 000 amperes on the four electrodes.

PROF. F. C. PHILLIPS:* Dr. Richards has given us a very interesting account of the process in places where water abounds. I should like to ask if its economy will justify the electric production of iron or steel in places far removed from available water power, like Pittsburgh?

THE AUTHOR: I have already said that in a place like Pittsburgh, where power is comparatively costly, I hardly think it will ever be used for making pig iron. But the possibilities of this new product, pig steel, if it should be used directly in making steel, may make it interesting for even such a citadel of conservatism as Pittsburgh.

PROF. S. L. GOODALE:† In case Dr. Richards' scheme is tried of cutting out the circulation of gases, would you not get too great a temperature in the roof of the arch, and would you not need to blow in some kind of a gas, as CO, to cool the arch of the furnace at the hottest part?

THE AUTHOR: I think we can cool the arch in a better way than blowing air or other gas under it. I think we can put in some water cooled plates, properly placed so as to protect the brickwork and prevent it being fused by the heat beneath. I think some such device could be adopted to preserve the arch as it is preserved in open hearth furnace, like we preserve the ports of our furnaces, without having to introduce the gas merely for cooling and preserving the arch.

I think it could be preserved in another way, and then it would certainly be desirable to cut out the circulation of the

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†Professor of Metallurgy, University of Pittsburgh.

gases. In fact in talking with Mr. Loeffler he said "We are trying this circulation of the gases, but I think we ought to find some other way of getting the heat up into the furnace." Only recently I commenced to figure out whether it would not pay to electrically heat the shaft to the low temperature required to cause reduction and cut out altogether the circulation of the gases and find some other way of preserving the shape of the arch.

PRESIDENT J. O. HANDY: I would like to ask Mr. Snyder whether the reference he made to the greater strength of iron castings melted in an electric furnace as compared with those made in other furnaces referred to commercial foundry practice or only to experimental work.

MR. F. T. SNYDER: I want to do some of the question asking myself. I want to ask Dr. Richards what is the good of having a shaft on the furnace. It is an obvious thing to copy the blast furnace, but why do you need it in an electric furnace? Why not do all the reducing in two or three feet instead of letting it fall thirty or forty feet?

THE AUTHOR: For the reason that when you reduce iron with carbon the first product of that reduction will be CO, and if you give it a chance to reduce some further iron oxide you may get some CO_2; and the more CO_2 you can get the less carbon you will need in the furnace and the more heat you will get from the combustion of the carbon. Therefore, it is desirable to get as much reduction by CO as posible. I do not mean to cut out the reduction by solid carbon. You have that to start with; but to get as much supplementary reduction by CO as possible. The more chance you give the CO to pass over red-hot iron oxide the more CO_2 you can produce and the less fuel you will need to use.

I believe the shaft can be cut down to very small dimensions. If you cut out the circulation and let the gases slowly filter upwards and give them time, I think six or eight feet may give them the chance to do all the reducing they can possibly do. I do not believe forty feet of shaft is necessary, but think that given six or eight feet of red-hot ore to pass through, you will get the maximum proportion of CO_2 possible, and so the maximum economy of fuel and power.

MR. F .T. SNYDER: I hesitate somewhat in view of Dr. Richards' reputation as a metallurgist, to differ from him. But I want to ask him whether the amount of CO_2 which you will get is not a function of the temperature rather than the height of the shaft. In other words if the temperature at the top is the same as at the top of this 40 ft. shaft, whether the proportion of CO_2 would not be approximately the same although the shaft is six feet high instead of 40 ft.

THE AUTHOR: I believe that other conditions being equal it would not, because the amount of reduction of iron ore by CO is a function of the time that it is in contact with the ore, at a proper temperature. It seems to me that the higher the shaft is kept at the reducing temperature, the more ore will be reduced by CO.

MR. F. T. SNYDER: Does not the equilibrium curve come in there?

THE AUTHOR: Equilibrium takes time.

PROF. F. C. PHILLIPS: I would ask Mr. Snyder whether the superiority of the metal called pig steel, is due to some difference in chemical composition or whether it is due to some cause not ascertainable?

MR. F. T. SNYDER: The physical fact is that steel which has not been blown, or which has not come through an open-hearth, gives more resistance to shock for the same specifications. It will probably stand double the drop hammer blows that steel bears which has been exposed to the amount of nitrogen which comes in a converter or open hearth.

THE AUTHOR: I should certainly recommend to any one making pig steel that they convert it into steel by the electric furnace and not by an open-hearth, certainly not by a bessemer furnace. Its prime quality being freedom from nitrogen, that quality would simply be wasted if you blow air through it in a bessemer converter. To conserve the freedom of the material from nitrogen as made in the electric furnace, it should be converted into steel in an electric furnace. The Swedes are building electric furnaces along side of their pig iron furnaces. The material will be tapped out of the pig iron furnace, carried over in ladles and put into the electric refining furnace and there refined, and it will never come in contact with the air, and therefore the steel will be entirely free from the nitrogen which is so prominently associated with bessemer steel and is present also in open hearth steel.

A MEMBER: Does the speaker think the electrolytic action set up has something to do with the purifying of the steel, making it better?

THE AUTHOR: No, because they always use the alternating current, which has practically no electrolytic action.

A MEMBER: If the furnace itself gets rid of sulphur and phosphorus, why do they use charcoal instead of soke?

THE AUTHOR: Simply because when charcoal is used there is less sulphur to get rid of than with coke. But they are going to use coke in some of the Norwegian furnaces because of the high price of charcoal and they will run with coke and expect to make a pig iron down to about 0.02 or 0.03 sulphur direct from the furnace, using coke.

I append a tabular statement of the first six month's running of the Trollhattan furnace:

Since the dates mentioned in the table, the furnace has been provided with six electrodes instead of four. The electrodes are screwed into each other and entirely consumed, a more powerful fan for circulating gases has been installed, also a dust catcher and scrubber to clean and purify the returned gas. As a result of these improvements, in the week of September 4th to 11th, 1912, the furnace consumed only 336 kg of carbon and 1736 kw. hours per ton of pig iron produced, with an electrode consumption of 5.5 kilos. The best feature of the whole is that many other improvements are possible, and will surely be made.

	PERIOD OF OPERATION					
	1910 Nov. 15 *	1910 Nov. 16 to 1911 Feb. 11	1911 Feb. 11 to Feb. 19	1911 Feb. 19 to Mar. 19	1911 Mar. 19 to Apr. 9	Total
Percent of Iron in Ore..	64.92	65.57	65.06	49.50	57.92	61.54
Percent of Iron in Charge	59.80	62.10	62.56	42.42	53.06	57.00
Slag per ton of Iron (kg.)	390.	205.	224.	780.	458.	327.
Charcoal Contents:						
Water (kg.)	.....	69.1	50.8	59.8	40.2	60.9
Gas (kg.)	.....	41.7	36.9	49.3	43.1	42.9
Ash (kg.)	.....	11.8	11.0	13.2	17.2	12.8
Carbon (kg.)	.....	293.1	277.6	323.4	325.7	301.4
Total kilogrammes	.....	415.7	376.3	445.7	426.2	418.0
Electric Power	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Time consumed working.	7.50	2,009.56	184.32	639.18	506.34	3,348.10
Time consumed in interruptions	.....	105.39	4.58	20.57	22.11	153.45
Total time	7.50	2,115.35	189.30	660.15	528.45	3,501.55
Average load (kw.)	1,121	1,319	1,694	1,017	1,733	1,344
Total kw. hours used .	8,780	2,651,029	312,601	650,480	877,706	4,500,596
Kw. hrs. per ton of Iron.	3,800	2,296	2,149	2,623	2,643	2,391
Iron per kw. year (tons).	2.31	3.82	4.08	3.34	3.31	3.66
Electrode consumption Per ton of Iron:						
Gross (kg.)	.....	11.24	10.84	9.19	7.45	10.28
Net (kg.)	.....	5.83	5.24	4.52	3.87	5.27

* Filling up of furnace.

[A partial bibliography of recent literature on Electric Furnace is appended and it is desired to acknowledge the assistance of the Technology Department of the Carnegie Library of Pittsburgh in its preparation.—EDITOR]

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Kershaw, John B. C. Electric furnace in iron and steel production. 1907.

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Pick, Waldemar & Conrad, Walter. Die herstellung von hochprozentigem ferro-silizium im elektrischen ofen. 1909.
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Stansfield, Alfred. The electric furnace, its evolution, theory and practice. 1907.
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Thompson, Maurice de Kay. Applied electrochemistry. 1911.
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Shows principles and reactions underlying operation.

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Stassano, Ernest. Application of the electric furnace to siderurgy—(translated) 24 p. 1909. (In Transactions of the American Electrochemical Society, v. 15, p. 63.)
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It is desired to acknowledge the assistance of the Technology Department of the Carnegie Library of Pittsburgh in the preparation of the above list.